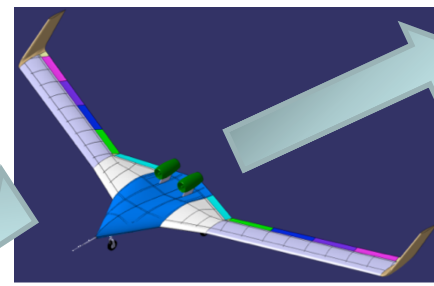
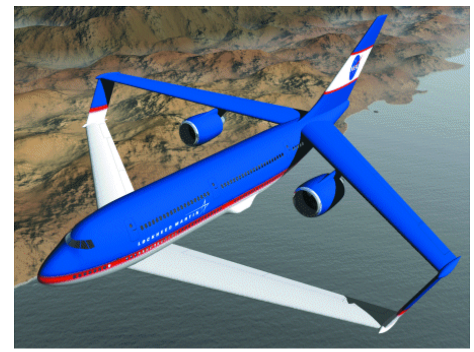
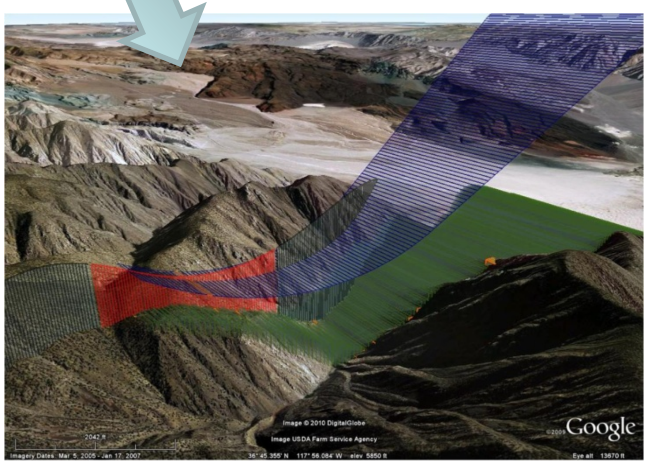
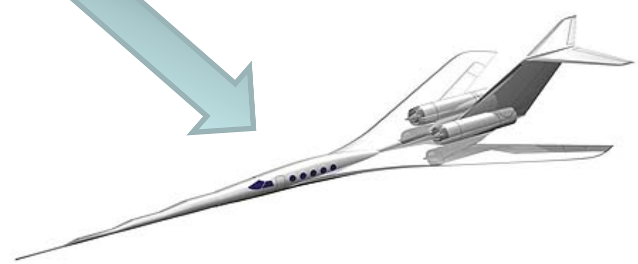
Flight Exploration of Advanced Integrated Concepts







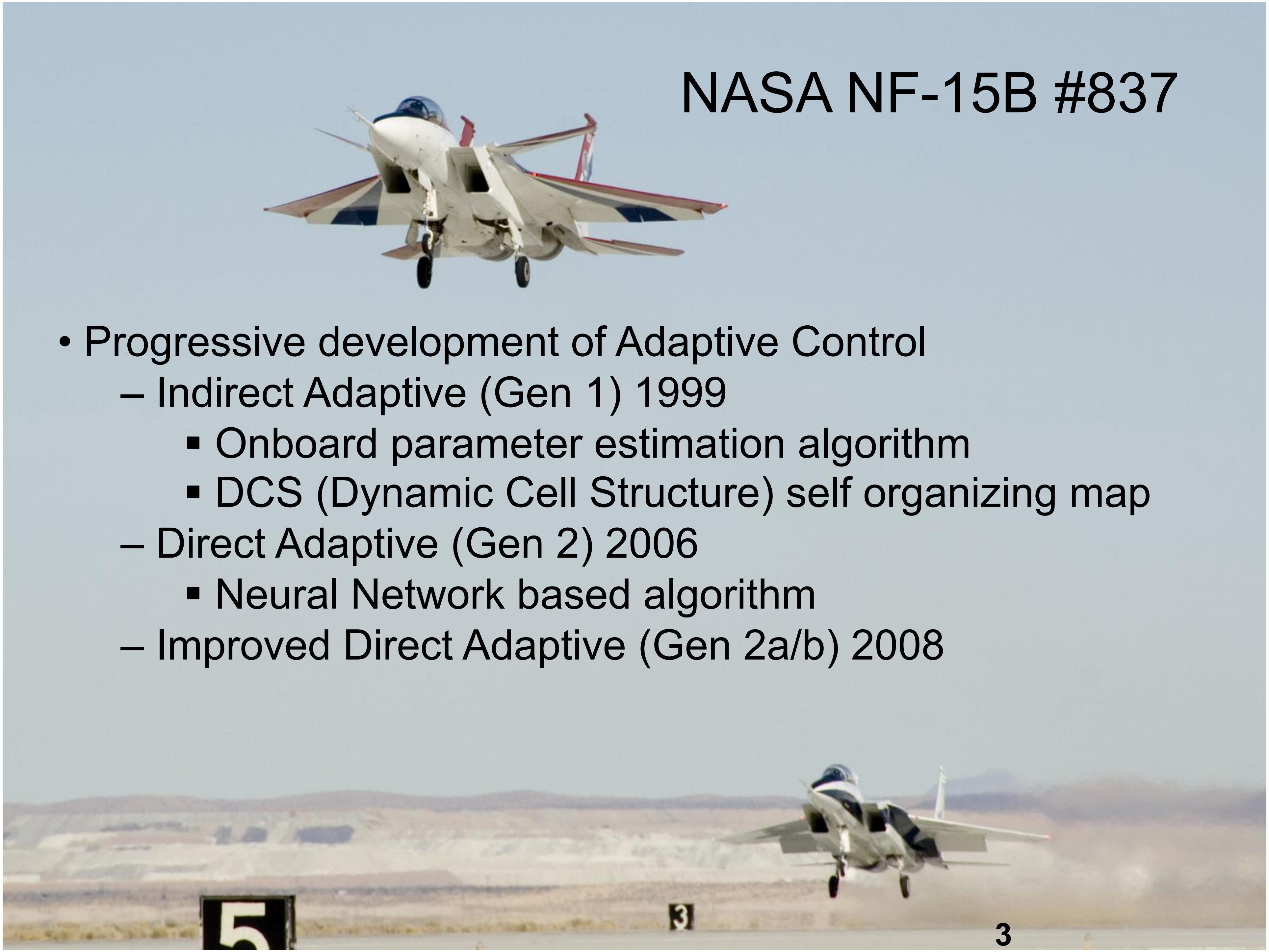


November 2010

Adaptive Controls Research

Integrated Resilient Aircraft Control (IRAC)

Aviation Safety Program



NASA NF-15B #837

- Progressive development of Adaptive Control
  - Indirect Adaptive (Gen 1) 1999
    - Onboard parameter estimation algorithm
    - DCS (Dynamic Cell Structure) self organizing map
  - Direct Adaptive (Gen 2) 2006
    - Neural Network based algorithm
  - Improved Direct Adaptive (Gen 2a/b) 2008

FY08 Highlights: Full-Scale Flight Research

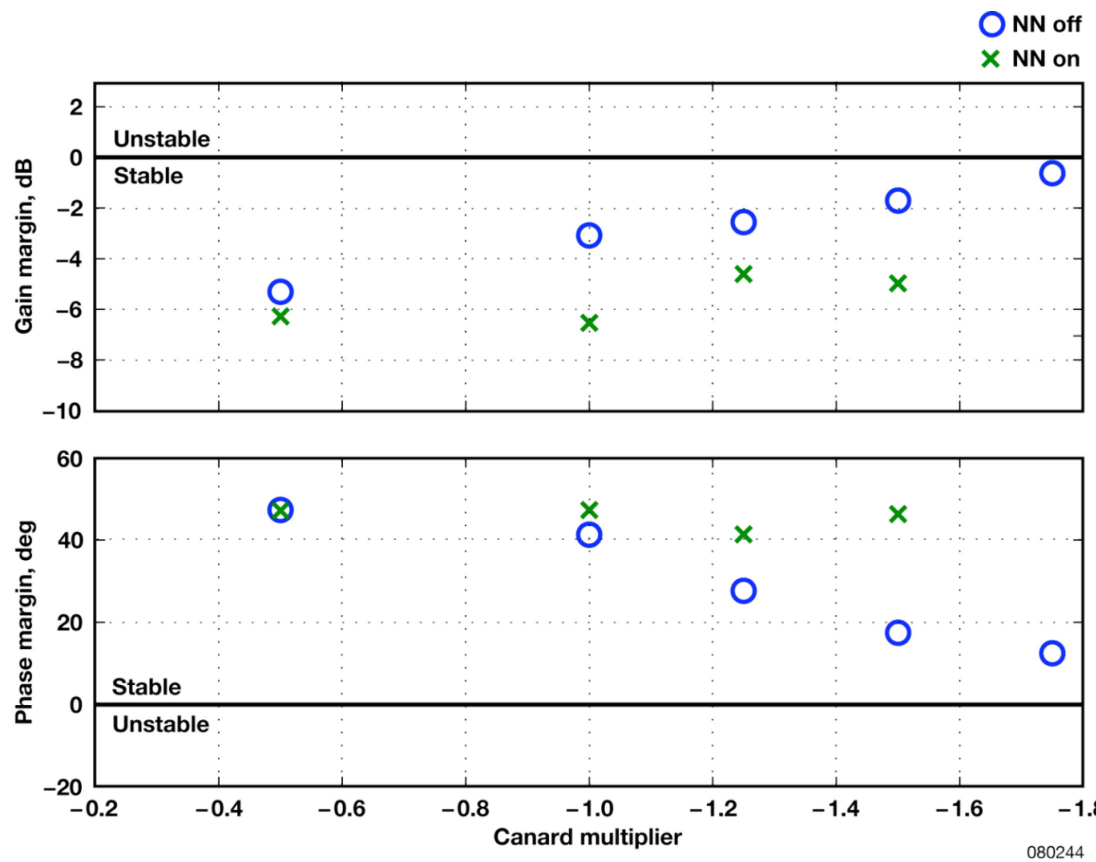
Title: Assessment of improved stability

Supporting Milestone: 4.1.1

Description: Full-Scale F-15 assessment of improved stability for aircraft in damage/failure conditions.

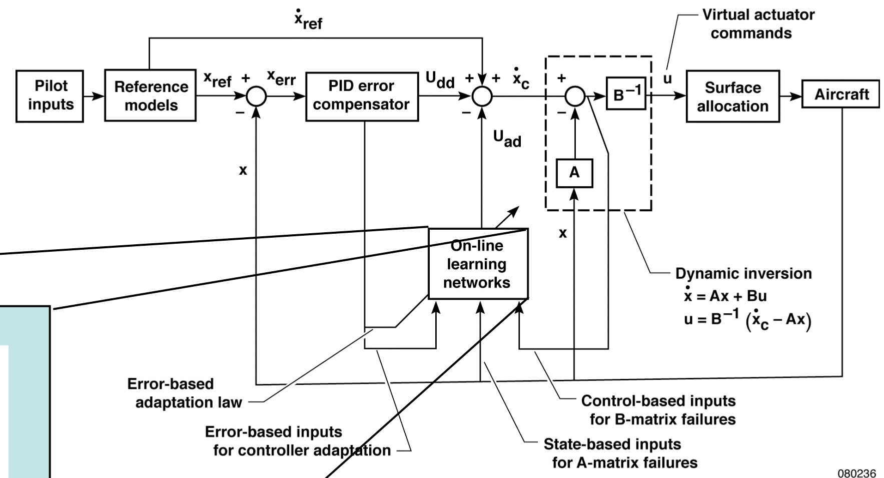
Outcome/Results:

Stability: 60% within a gain margin (GM) greater than 5dB and phase margin (PM) greater than 35 degrees; 30% within a gain margin in the range of 3 dB to 5dB and phase margin in the range of 25 to 35 degrees.

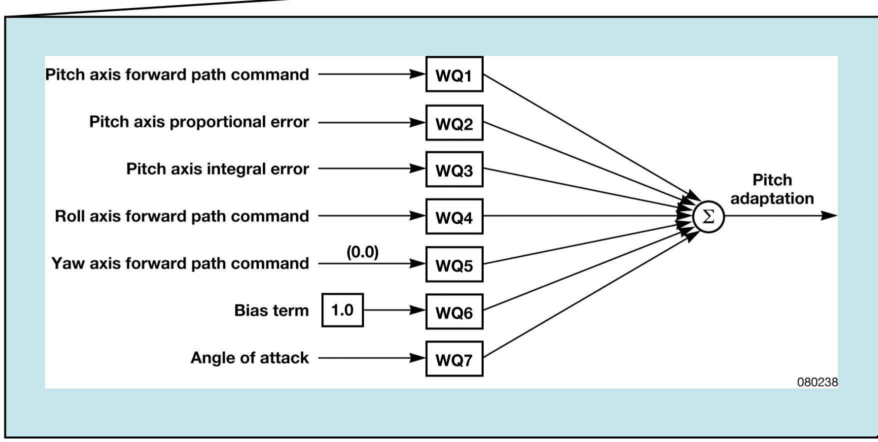


Full-Scale Flight Research Products

- **Flight validated direct adaptive control architecture**
  - Documentation and description of specific control architecture
  - Pilot handling qualities ratings with and without failures
  - Flight measured stability margins
  - Statistical measurements of model-following performance



Adaptive Algorithms



Integration with Control System

F-18 FAST

- **Full-scale Advanced Systems Testbed**
  - Initial flights April 2010 – RFCS replication control laws
  - Initial ARTS IV flights August 2010
  - Baseline Nonlinear Dynamic Inversion Controller Sept 2010
  - MMRAC simplified adaptive system – coming soon …

Video

- Show video {previously approved by export control}

FAST Research Avionics Capabilities

- Dedicated Ghz processor for experiment
- Shell & process for Simulink autocode (or c-code)
- Can control commands to:

  All aero surfaces (except speed brake)

  All pilot inputs

  Both engine throttles independently

- Limit checks done by Class A software in RFCS
- Potential for Class A experiment (dual ARTS IV or in quad RFCS) – take to landing?
- Tons of research instrumentation parameters (mostly related to structures)
- Simulated failure of multiple control surfaces

IRAC Full Scale Flight Experiment Peer Review Selection Process

- Completed workshop at AIAA GNC in Chicago
  - Very good feedback and discussion
- Decision to emphasize three adaptive system Focus Areas:

  1 - Simplified Adaptive System
    - Analyzable
    - V&V able

  2 – Pilot Interaction

  3 - Structural Interaction
    - Static structures – fiber optic deflection measurement system
    - Aero-servo-elasticity – adaptive feedback to eliminate structural modes from sensed motion

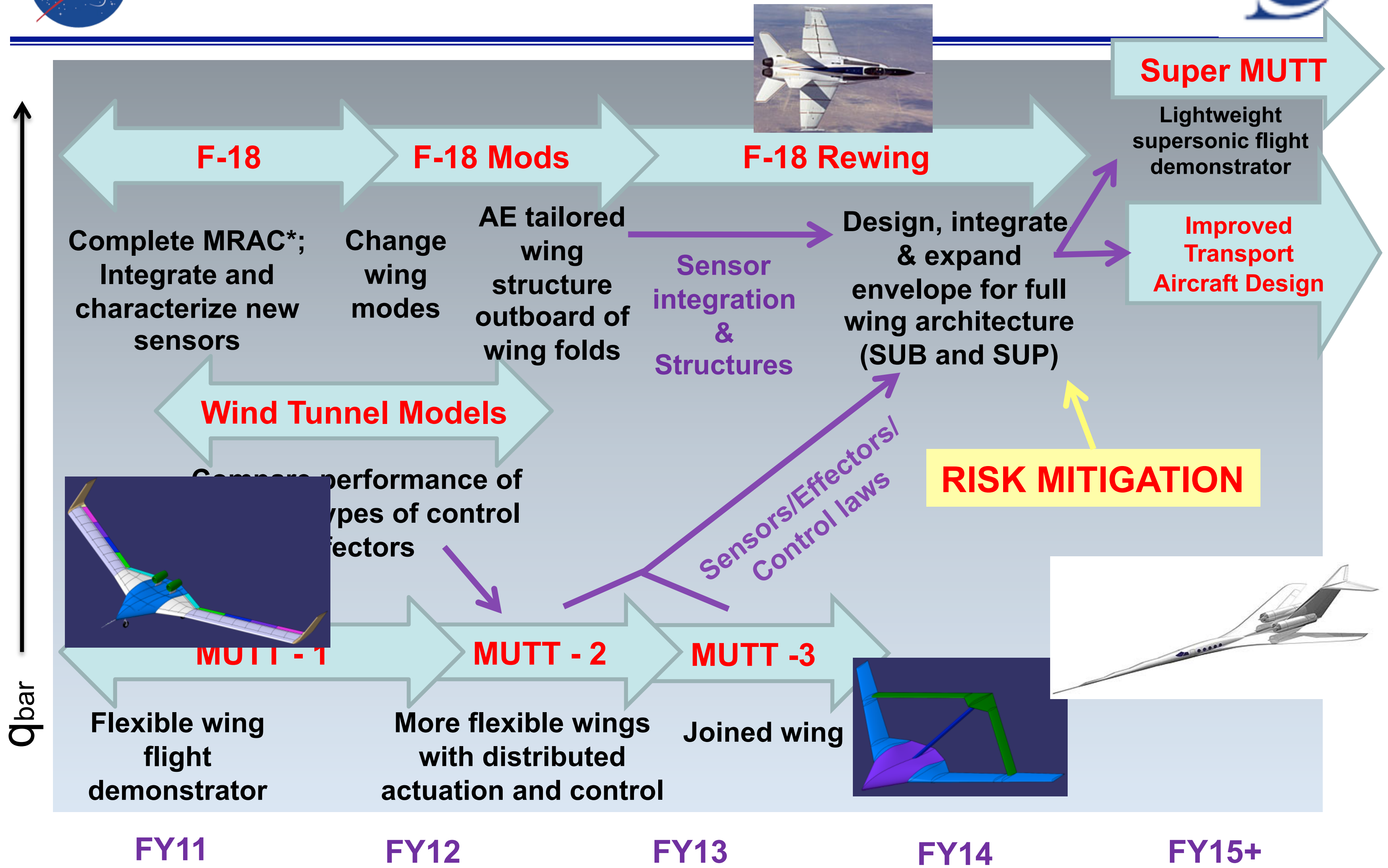
Workshop Developed Focus Areas

- **Simplified adaptive system**
  - Goal: system that is more acceptable to the aerospace community in terms of complexity and testability
  - Benefit:
    - Gain experience in verification & validation of adaptive systems
    - Prove system stability.
- **Pilot – adaptive controller interaction**
  - Goal: provide mechanisms for feedback both to and from the pilot to allow for better understanding of what the adaptive system is doing and also some control over how much or little the system adapts
  - Goal: provide the capability to predict and prevent adverse interactions between the pilot and the adaptive system
  - Benefit:
    - Reduce potential Pilot Induced Oscillations tendencies due to aircraft damage
    - Reduce cross-axis coupling due to a failure.
- **Integration with vehicle structure**
  - Goal: alleviate a major roadblock to adaptive system implementation by providing information that allows the adaptive system to impose constraints that keep the aircraft within structural limits and provide methods that reduce the potential for adverse aeroservoelastic interactions
  - Benefit:
    - Prevention of static and dynamic structural over-load.

Future Direction:

Beyond Rigid Body Control

Proposed Research Roadmap



(Source: Chris Jutte – 9-10-10)

*(Model Referenced Adaptive Control)

Development Areas

- Modeling
  - Static Structures – large margins, very conservative
  - Dynamics – conservative notch filter designs result in large feedback phase loss
  - Elastically tailored structures
- Sensors
  - Fiber Optic Shape Sensing (FOSS)
  - Fly-by-feel (hot films and beyond)
  - Others …
- Actuation
  - Potentially very high bandwidth requirements
  - Piezoelectric, mems, others …
- Control Algorithms
  - Balance structural shape, structural load, dynamic interaction suppression, with rigid body performance requirements

Relevant Customers

- **Fundamental Aero**
  - Employ “Fly by Feel” (Tao) sensors to determine real time the wing center of pressure distribution (and hence the driving forces on the wings)
  - Employ Fiber optic Shape Sensors (FOSS) to determine the structural response to these (and other forces).
  - Develop an appropriate control algorithm to use this data to enable lighter-weight more flexible structures
  - Refine ASE modeling and predictive techniques using in-flight modal measurement and identification

Relevant Customers

- **Aviation Safety**
  - Employ "Fly by Feel" (Tao) sensors to provide reduced response to gusts, wind shear, and wake encounter
  - Employ Fiber optic Shape Sensors (FOSS) and investigate the potential for use in detection of internal structural failure based on a change in shape or dynamic modal characteristics
  - Develop appropriate control algorithms to use structural feedback to control within damaged aircraft limits
  - Develop energy management techniques and pilot warning systems to reduce accidents in the approach and landing phase

Relevant Customers

- **Supersonics**
  - The development of engine and airframe models to capture effects of airframe aeroelastic dynamics on the propulsion performance and then feed propulsion performance back to control the airframe response
  - Develop an appropriate control algorithm incorporating FOSS feedback to provide the ability to accurately control vehicle shape to mitigate sonic boom signature
- **AFRL**
  - Monitoring and Control of Flexible Structures for surface-mounted Phased Array Radar Applications:
  - AFRL “Sensorcraft” Type Technologies
  - Future lighter-weight more flexible structures
  - Targeted aero elastic structural modeling validation
  - Flight evaluation of new sensor technologies
  - Design and flight demonstration of structural feedback and shape control techniques
- **OCT, DARPA, Navy, Exploration Directorate …**

Concluding Remarks

- There are many customers for research in the area of advanced integrated concepts
- The F-18 FAST vehicle provides an excellent capability for flight exploration in this area
- The payoff will be validation or invalidation of some fundamental approaches to the integrated control problem

To Fly What Others Imagine …